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Indian Standard

CRITERIA FOR DESIGN OF STEEL BINS FOR STORAGE OF BULK MATERIALS

PART II DESIGN CRITERIA

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MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 8

April 1980

Indian Standard

CRITERIA FOR DESIGN OF STEEL BINS FOR STORAGE OF BULK MATERIALS

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Indian Standard

CRITERIA FOR DESIGN OF STEEL BINS FOR STORAGE OF BULK MATERIALS

PART II DESIGN CRITERIA

0. FOREWORD

0.1 This Indian Standard (Part II) was adopted by the Indian Standards Institution on 15 May 1979, after the draft finalized by the Structural Engineering Sectional Committee had been approved by the Structural and Metals Division Council and the Civil Engineering Division Council.

0.2 Bins are known as silos if they have circular or polygonal shape in plan. When square or rectangular in plan they are known as bunkers. In this standard bin shall mean both silos and bunkers unless otherwise stated.

0.3 The functions of bins as storage structures are very important in power stations, fertilizer complexes, steel plants, cement plants, and similar industries for efficient storage and use of bulk material both in granular and powdery form. On the agricultural front bins are used to store food grains for ensuring their supply all through the year. Bulk storage of material in bins has certain advantages over other forms of storage. Therefore an Indian Standard on this subject has been a long felt need and this standard has been aimed at giving the necessary guidance in the analysis and design of steel bins for storing various materials of different characteristics and flow properties.

0.4 Bins have been designed on the basis of Janssen's Theory (with modifications to the original). From experimental investigations and a study of the performance of the existing bins it has been noticed that the pressure distribution is influenced by the size and shape of the material to be stored (that is granular or powdery), moisture and temperature, bulk density, which in turn is affected by storage and flow characteristics. Besides there is an increase in the imposed loads during filling and emptying, the latter being more predominant.

0.5 For reasons mentioned above in the bins designed by conventional methods, materials do not easily flow due to arching and piping. This requires frequent poking-manually, pneumatically with steam or by other mechanical means. With research data available, this problem has been successfully solved by adopting mass flow or funnel flow bins where the shape of the bin hopper and size of the openings are based on the flow properties of the stored material.

0.6 In order to deal with the subject in an effective manner this standard has been prepared in three parts namely:

Part I General requirements and assessment of loads

Part II Design criteria

Part III Bins designed for mass flow and funnel flow

0.7 This standard keeps in view the practices being followed in the country and elsewhere in this field. Assistance has also been derived from the following publications:

DIN 1055 (Sheet 6) Design loads for building — Loads in silo/bins. Deutscher Normenausschuss.

PIPEPER (K) and WENZEL (F). Pressure distribution in bins (in German). 1964. Verlag Von Wilhelm Ernst & Sohn, Berlin, Munchen.

REISNER (W) and ROTHE (M E). Bins and bunkers for handling bulk materials. Trans-Tech. Publication, Ohio, USA.

LAMBERT (F E). The theory and practical design of bunkers. The British Constructional Steelwork Associations Ltd, London.

JENIKE (A W). Storage and flow of solids, *Bull* 123. 1964. Utah Engineering Experiment Station, University of Utah, Utah, USA.

0.8 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard (Part II) deals with the criteria for design of steel bins and analysis of forces for granular and powdery materials for different bin shapes.

1.2 This standard covers circular, polygonal and interstice bins.

---

*Rules for rounding off numerical values (*revised*).

2. TERMINOLOGY

2.1 For the purpose of this standard the definitions given in Part I in addition to the following definitions shall apply.

2.1.1 *Shallow Beam* — A beam in which the depth (height) to span ratio is less than 0·5. The stress distribution may be assumed linear.

2.1.2 *Deep Beam*— A beam in which the depth (height) to span ratio is greater than or equal to 0·5. The stress distribution is not linear.

2.1.3 *Corner Plate* — A plate normally in the shape of a quadrant of a circle provided at the corners (that is at the junction of the walls) of a steel bin for smooth flow of material.

3. NOTATION

3.1 For the purpose of this standard the notations given in Part I shall apply in addition to the following:

P_1, P_2, P_3 = Total horizontal loads due to pressure P_h

W_1, W_2, W_3 = Total vertical loads due to pressure P_v

M = Moment in the stiffener

T = Tension in the stiffener

H, H' = Bursting force

L, B = Dimensions of the stiffener

I_1, I_2 = Moment of inertia of the stiffener

I_a, I_b = Moment of inertia of the shorter wall and longer wall of the bin

s = Spacing between stiffener

t = Thickness of wall plate

T_H = Tension due to circumferential stress on unit length of the silo wall

T_L = Tension due to longitudinal stress per unit length of circumference

r_1 = Radius of hopper at the plane under consideration

r_2 = Mean radius of ring beam

h_1, h_2, x, x', y = Dimensions of bunker and hopper wall as shown in Fig. 1 and 2

R_N = Normal load acting on the sloping wall of hopper

R_A, R_B, R_V = Reactions

P_n = Normal pressure

P_{tB}, P_{tC} = Tangential pressures

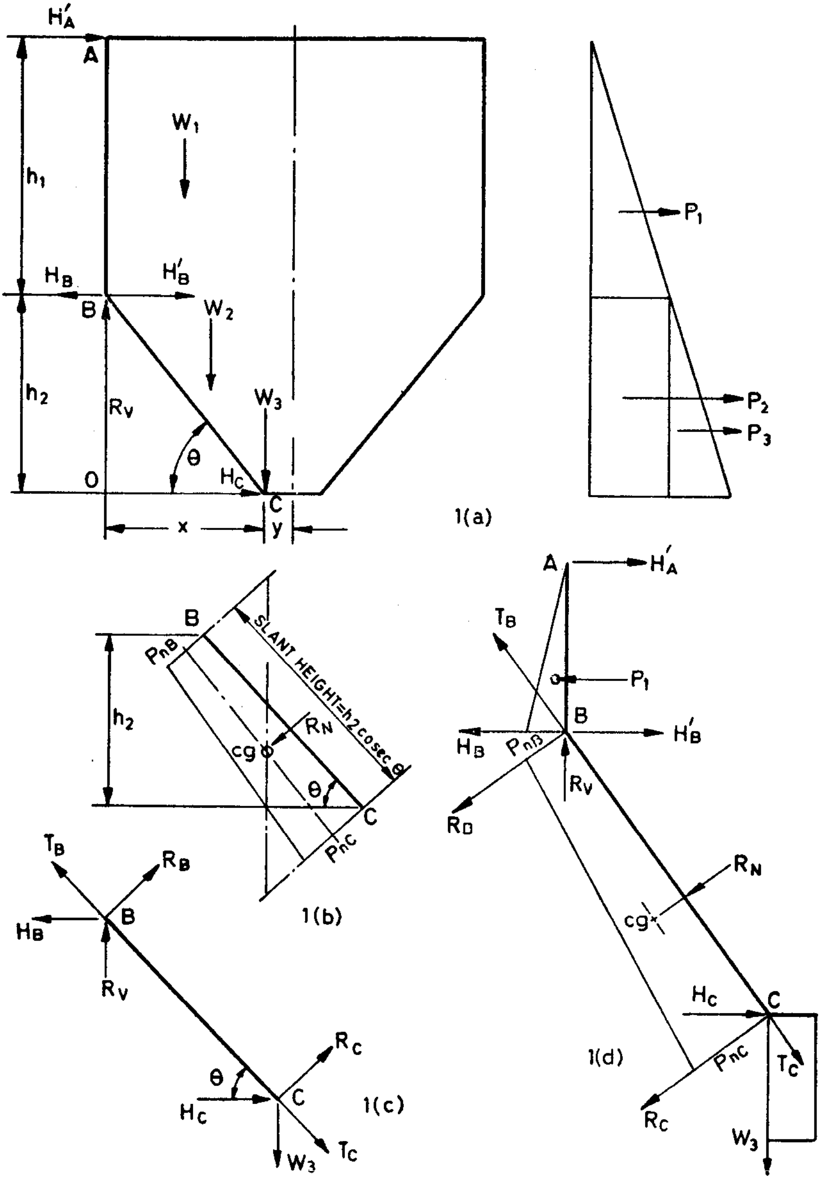

Fig. 1 Forces in Rectangular Symmetrical Bunker

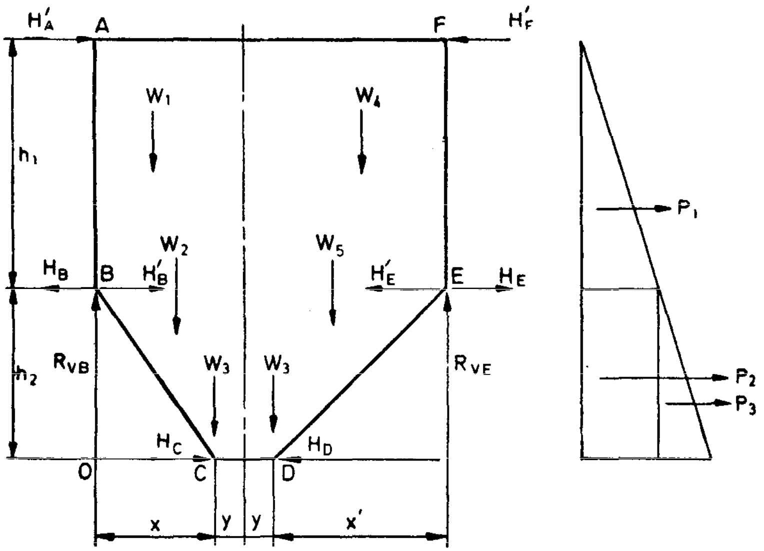

FIG. 2 FORCES IN RECTANGULAR UNSYMMETRICAL BUNKER

4. LOADS

4.1 Dead and Live Loads — The dead and live loads on the bin structures shall be as given in IS : 875-1964*. The bulk density of various commonly stores materials are given in Table 2 of Part I.

4.1.1 Loads due to the stored material in the bin shall be assessed according to **6** of Part I of the standard.

4.2 Wind Load — Unless otherwise specified wind load on bins shall be calculated in accordance with IS : 875-1964*.

4.3 Seismic Forces — Unless otherwise specified seismic loads shall be calculated in accordance with IS : 1893-1975†.

NOTE — Wind and seismic forces shall not be assumed to act simultaneously.

4.4 The effect of the super-imposed loads due to material handling and transportation machinery shall also be considered in addition to the loads specified in **4.1** to **4.3**.

---

*Code of practice for structural safety of buildings: Loading standards.

†Criteria for earthquake resistant design of structures (*third revision*).

5. MATERIAL

5.1 Structural Steel — All structural steel used in the construction of bins shall conform to IS : 226-1975[*], IS : 961-1975[†] and IS : 2062-1969[‡] as appropriate.

5.2 Rivets — Rivets before fabrication shall comply with IS : 1148-1973[§] or IS : 1149-1973[||].

5.3 Bolts and Nuts — All bolts and nuts shall conform to IS : 1364-1967[¶] and IS : 1367-1967[**].

5.4 Washers — Washers shall conform to IS : 2016-1967[††].

5.5 High Strength Friction Grip Fastener — High strength friction grip fasteners shall conform to IS : 3757-1972[‡‡].

5.6 Electrodes Filler Material and Welding Consumables — Electrodes, filler material, flux, etc, used in welding shall conform to:

IS : 814 (Part I)-1974 Specification for covered electrodes for metal arc welding of structural steel: Part I For welding products other than sheets (*fourth revision*)

IS : 814 (Part II)-1974 Specification for covered electrodes for metal arc welding of structural steel: Part II For welding sheets (*fourth revision*)

IS : 1278-1972 Specification for filler rods and wires for gas welding (*second revision*)

IS : 3613-1974 Acceptance tests for wire-flux combinations for submerged-arc welding of structural steels (*first revision*)

IS : 6419-1971 Filler rods and wires for inert gas welding of ferritic steels

IS : 7280-1974 Base wire electrodes for submerged arc welding of structural steels

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[*] Structural steel (standard quality) (*fifth revision*).

[†] Structural steel (high tensile) (*second revision*).

[‡] Structural steel (fusion welding quality) (*first revision*).

[§] Specification for hot rolled steel rivet bars (up to 40 mm diameter) for structural purposes (*second revision*).

[||] Specification for high tensile steel rivet bars for structural purposes (*second revision*).

[¶] Precision and semi-precision hexagon bolts, screws, nuts and lock nuts (diameter range 6 to 39 mm) (*first revision*).

[**] Technical supply conditions for threaded fasteners (*first revision*).

[††] Specification for plain washers (*first revision*).

[‡‡] High-tensile friction grip bolts (*first revision*).

5.7 Other materials used in association with steel work shall, where appropriate Indian Standard exists, conform to such standards.

6. PERMISSIBLE STRESSES

6.1 Permissible stresses shall be as specified in IS : 800-1962*.

7. GENERAL DESIGN REQUIREMENTS

7.1 General — The dimensions, shapes and layout of steel bins shall conform to the relevant provisions of Part I of this standard.

7.2 Doors and Openings — Openings for filling, emptying, aeration, and for instruments indicating the height of the stored material, quantity of flow, weight of stored material, etc, shall be provided. Manual access shall be suitably provided.

7.2.1 Openings shall preferably be avoided in the zones of critical stress.

7.3 Supports — The arrangements for supporting the walls of a bin shall depend upon the layout, the outlet openings, positions of the draw off conveyors, type of bin bottom, etc. The design of supporting structures shall generally conform to the requirements of IS : 800-1962*.

7.3.1 If the bins form part of a building like power station, they shall be suitably connected to the beams and columns of such buildings.

7.4 Foundations

7.4.1 The type of foundation for the storage bins shall be decided taking into consideration the layout, site conditions, nature of soil and the load transferred.

7.4.2 The bin structure shall rest on a reinforced concrete raft foundation, or pile foundations or isolated footings depending upon the soil conditions. Site investigation for foundation shall be carried out in accordance with IS : 1892-1962†.

7.4.3 In case the reinforced concrete raft is to be laid over the piles the top of the mat shall be at the plinth level.

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*Code of practice for use of structural steel in general building construction (*revised*).

†Code of practice for site investigations for foundations.

7.4.4 Design of foundation shall be carried out in accordance with the provisions of IS : 456-1978*, IS : 1080-1962†, IS : 2911 (Part I)-1964‡ and IS : 2950 (Part I)-1973§ as appropriate.

8. GENERAL DESIGN CRITERIA

8.1 For the design of steel bins the provisions contained in IS : 800-1962‖ shall be applicable in conjunction with the provisions of this standard.

9. ANALYSIS OF FORCES AND MOMENTS OF BINS STRUCTURES

9.0 General — The normally used method of analyzing single compartment bins is specified in this standard. The intensity of load at any particular depth is considered uniform.

9.1 Bunkers with Horizontally Spanning Walls — If the bunker is rectangular and the moments of inertia of the side walls are different, the value of corner moment M at any horizontal cross section of bunker shall be calculated as follows:

$$M = \frac{-P}{12}\left[\frac{b^3 I_a + a^3 I_b}{b.I_a + a I_b}\right]$$

where

P = calculated intensity of horizontal wall loads due to stored material assumed to be uniformly acting on any horizontal cross section of bunker

a = breadth of bin

b = length of bin

I_b = moment of inertia of longer wall

I_a = moment of inertia of the shorter wall

If $I_a = I_b$

$$M = \frac{-P}{12}\left[\frac{a^3 + b^3}{a + b}\right]$$

If the bin is square, that is if $a = b$ then

$$M = \frac{-Pa^2}{12} = -0{\cdot}083\ Pa^2$$

NOTE — The horizontal pressures vary along the height of the bunker wall. Hence the bending moments and tensions also vary likewise.

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*Code of practice for plain and reinforced concrete (*third revision*).

†Code of practice for design and construction of simple spread foundations.

‡Code of practice for design and construction of pile foundations: Part I Load-bearing concrete piles.

§Code of practice for design and construction of raft foundations: Part I Design (*first revision*).

‖Code of practice for use of structural steel in general building construction (*revised*).

9.2 Symmetrical Bunkers with Trough Bottom — In view of the symmetry, only half the bunker is analyzed considering unit length of the bin [*see* Fig. 1(a)]. Above the waist, the two forces causing bursting are:

$$H'_A = \frac{P_1}{3}$$

$$H'_B = \frac{2P_1}{3}$$

The bursting force across the waist and at the discharge orifice level are:

$$H_B = \frac{1}{h_2}\left[W_1\frac{x}{2} + W_2\frac{2x}{3} + W_3\,x - P_2\frac{h_2}{2} - P_3\frac{h_2}{3}\right]$$

$$H_C = \frac{1}{h_2}\left[W_1\frac{x}{2} + W_2\frac{2x}{3} + W_3\,x + P_2\frac{h_2}{2} + P_3\frac{2h_2}{3}\right]$$

where

P_1, P_2, and P_3 are total horizontal forces as shown in Fig. 1(a) due to pressure P_h (*see* **6** of Part I of this standard); and

W_1, W_2, W_3 are total vertical loads as shown in Fig. 1(a) due to pressure P_V (*see* **6** of Part I of this standard).

9.2.1 *Sloping Side of the Hopper* — If P_{nB} and P_{nC} are the normal pressures at B and C the total normal load acting on the sloping wall is:

$$R_N = \left[\frac{P_{nC} + P_{nB}}{2}\right] \times \text{Slant height}$$

$$= \left[\frac{P_{nC} + P_{nB}}{2}\right] \times h_2 \operatorname{cosec} \theta$$

R_N acts through the centre of gravity of the pressure diagram as shown in Fig. 1(b).

The vertical and horizontal reactions at B and C may be resolved to give the normal and tangential components required to design the trough stiffeners [*see* Fig. 1(c)].

$$R_B = R_V \operatorname{Cos} \theta - H_B \operatorname{Sin} \theta$$

$$R_C = H_C \operatorname{Sin} \theta - W_3 \operatorname{Cos} \theta$$

$$T_B = R_V \operatorname{Sin} \theta + H_B \operatorname{Cos} \theta$$

$$T_C = H_C \operatorname{Cos} \theta + W_3 \operatorname{Sin} \theta$$

and $R_N = R_B + R_C$

where

$$R_V = W_1 + W_2 + W_3$$

The final forces and pressures required for the design calculations are given in Fig. 1(d).

9.3 Asymmetrical Bunker — The algebraic solutions given for symmetrical bunker may also be applied to bunkers which are not symmetrical about a vertical line passing through the middle of the discharge opening. Such an arrangement with all vertical and horizontal forces is shown in Fig. 2.

Above the waist *BE* the horizontal forces have the same meaning as outlined for the symmetrical case, that is:

$$H'_A = H'_F = \frac{P_1}{3}$$

$$H'_B = H'_E = \frac{2P_1}{3}$$

Below the waist the following differences should be noted:

$$\begin{array}{ccc} H_B & \neq & H_E \\ H_C & \neq & H_D \\ R_{VB} & \neq & R_{VE} \end{array}$$

For the steepest side:

$$H_B = \frac{1}{h_2}\left[W_1\frac{x}{2} + W_2\frac{2x}{3} + W_3\,x - P_2\frac{h_2}{2} - P_3\frac{h_2}{3}\right] \text{ and}$$

$$H_C = \frac{1}{h_2}\left[W_1\frac{x}{2} + W_2\frac{2x}{3} + W_3x + P_2\frac{h_2}{2} + P_3\frac{2h_2}{3}\right]$$

For the less steep side:

$$H_E = \frac{1}{h_2}\left[W_4\frac{x'}{2} + W_5\frac{2x'}{3} + W_3\,x' - P_2\frac{h_2}{2} - P_3\frac{h_2}{3}\right]$$

$$H_D = \frac{1}{h_2}\left[W_4\frac{x'}{2} + W_5\frac{2x'}{3} + W_3\,x' + P_2\frac{h_2}{2} + P_3\frac{2h_2}{3}\right]$$

The vertical reactions are:

$$R_{VB} = W_1 + W_2 + W_3$$
$$R_{VE} = W_4 + W_5 + W_3$$

It should be noted that the reactions R_{VB} and R_{VE} are not the simply supported beam reactions. This is because there is an out-of-balance horizontal reaction at the outlet having the value

$$H = H_D - H_C$$

Below the waist the horizontal forces should be in equilibrium, that is:

$$H_B + P_2 + P_3 - H_C = 0,$$
$$H_E + P_2 + P_3 - H_D = 0, \text{ and}$$
$$H_D - H_C = H_E - H_B.$$

The procedure for calculating the normal and tangential pressures and reactions is the same as for symmetrical bins.

9.4 Silos — The hoop tension T_H is calculated from the following formula (*see* Fig. 3):

$$T_H = \frac{P_n . d}{2}$$

9.4.1 Depending upon the manner in which the silo is supported there may also be a longitudinal tension in the cylindrical portion.

If the silo is supported at *bb'b* (*see* Fig. 3A) the longitudinal tension in the shell immediately below this plane will be due to the weight of the contents plus the self weight of that part of the shell below *bb'b*. If W_d is the weight of the contents plus an allowance for self weight below *bb'b*, then the longitudinal tension T_L per unit length of circumference shall be:

$$T_L = \frac{W_d}{\pi . d}$$

If the support is at *AA'*, W_d will be the total combined weight of the contents and the weight of silo. However, if the silo is supported at the waist *BB'* which is preferable, then longitudinal tension shall be neglected for the analysis of cylindrical portion of the silo.

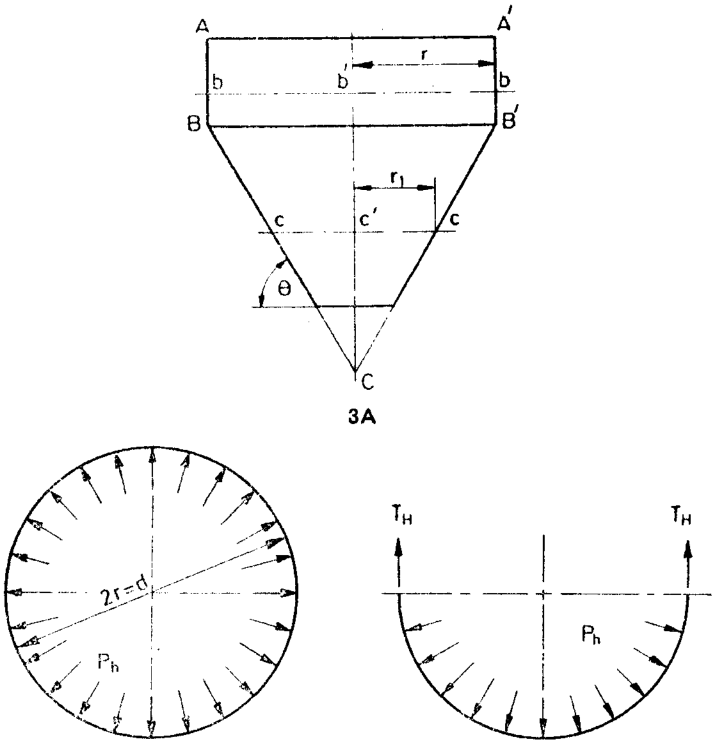
9.5 Hopper Bottom — The normal pressure P_n and tangential pressure P_t at any point on the hopper shall be calculated as follow:

$$P_n = P_v \text{Cos}^2 \theta + P_h \text{Sin}^2 \theta + W_s \text{Cos} \theta$$
$$P_t = P_v (1 - \lambda) \text{Sin} \theta \text{Cos} \theta + W_s \text{Sin} \theta$$
$$\text{or} \quad = (P_v - P_h) \text{Sin} \theta \text{Cos} \theta + W_s \text{Sin} \theta$$

where

W_s = self weight of hopper per unit area.

9.5.1 *Conical Hopper* — Conical hoppers are generally subjected to meridional and hoop tensions as the support is normally never below the waist (*see* Fig. 3).



3A

3B

3C

FIG. 3 PRESSURE IN SILOS

The hoop tension T_H at any level of the conical hopper shell be calculated from the following formula:

$T_H = P_n \, r_1 \text{ Cosec } \theta$

The hoop tension will depend upon the vertical pressure acting on the plate *cc'c* plus the weight of material and the shell immediately below the plane. If this total vertical load is W_t, then the longitudinal tension is:

$$T_L = \frac{W_t}{2\pi r_1} \text{ Cosec } \theta$$

where

r_1 = radius at the plane under consideration.

T_L is maximum at the waist BB' (*see* Fig. 3) where W_t equals the total weight of the contents plus the self weight of the cone. Likewise the minimum tension will occur at the outlet.

9.5.2 *Pyramidal Hopper* — Pyramidal hoppers are subjected to bending moments and direct tension in addition to meridional (longitudinal) tension along the slope. The hoppers of polygonal bins shall be analyzed by considering each horizontal strip subjected to normal design pressure P_n calculated as per **9.5**. The meridional tension shall be calculated in the same way as per conical hopper (*see* **9.5.1**).

9.5.3 *Flat Bottom or Level Bottom* — When no separate hopper is provided, the flat bottom will be a flat plate or slab and will be subjected to a maximum pressure equal to P_V.

9.5.4 *Special Shapes* — The hoppers may be of special shapes to suit particular requirements like hopper for interstice bins and hoppers with eccentric discharge. In such cases the design should be based on sound engineering practice.

9.6 Multiple Compartments

9.6.1 Multiple compartments are normally provided in rectangular bins. The bin should be designed taking into consideration the worst combination of loads in different compartments.

10. STRUCTURAL DESIGN RECOMMENDATIONS FOR BUNKERS

10.1 General — The forces set up in a bunker induce direct, shear and bending stresses in its various parts. However, because of the shape it is not economical to design the skin plate to resist all these stresses.

10.1.1 The skin plate which form the bin wall is designed to span between suitably positioned stiffeners which may be vertical or horizontal depending upon the layout. Normally these stiffeners are arranged to act in the vertical plane.

10.2 Skin Plate — The skin plate may be designed as a beam either simply supported or continuous between the stiffeners, which in turn also act as beams, but spanning at right angles to the designed direction of skin plate.

10.2.1 The skin plates spanning between stiffeners are subjected to bending, shear and longitudinal stresses. Normally the plate is designed for bending, the shear being neglected. The longitudinal tension is taken up on the stiffeners which may include a portion of the plate.

10.2.2 The plate generally spans in two directions simultaneously. Provided the ratio of length to width of the plate is less than 3 the advantage may be taken of two-way bending.

10.3 Side Walls — The side wall shall be designed as structure carrying both vertical and horizontal loads. Based on the intensity of loads the stiffeners shall be provided either in the horizontal or in vertical planes. Hoppers are provided based on the need of a desired flow pattern and control on flow of stored material. Hoppers are also designed like a side wall with stiffeners.

10.3.1 The side walls may be designed as deep beams if the ratio of depth to span is more than 0·5. The design loads shall include vertical and horizontal forces, and the longitudinal tension caused by the filler material.

10.3.2 A convenient method of designing the side wall is to proportion the skin plate for side pressure only with stiffeners arranged either vertically or horizontally to suit the layout. The trough or cone reactions may then be carried on a suitably designed beam situated immediately at the bottom of the wall.

10.3.3 Vertical stiffeners when they extend for the full uninterrupted depth of the wall, and are subjected to a triangular load distribution shall be designed to resist a bending moment of $0{\cdot}0641\ P_b.L^2$, where P_b is the mean horizontal load on the uninterrupted depth of the stiffener. If they are interrupted due to the presence of horizontal stiffeners the bending moment for each separate length may be calculated as indicated in **10.4**.

10.3.4 If the stiffeners are arranged horizontally they will be subjected to a uniformly distributed load, and may be designed either as simply supported beams trimming into an extension of the corner support column, or where this is not possible as closed rings. In addition to the bending moment, horizontal stiffeners will also be subjected to direct tension due to the pressure on the wall at right angles to the wall actually being designed.

10.3.5 Side wall stiffeners may be proportioned to include part of the skin plate (*see* IS : 800-1962*).

10.3.6 In Fig. 4 is shown a horizontal stiffener treated as a closed rectangular ring.

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*Code of practice for use of structural steel in general building construction (*revised*).

10.3.6.1 The ring is in equilibrium (*see* Fig. 4A) under the load P'_s which is equal to the average pressure at the level being considered multiplied by the distance between the stiffeners. As the ring is completely symmetrical about the point O, it is convenient to analyze one quadrant only. In Fig. 4B this quadrant is shown under the influence of the load P'_S; moments M_A, M_B and M_C and tension T_A and T_C, may be calculated as follows:

$$T_A = \frac{P'_s B}{2} \text{ and}$$

$$T_B = \frac{P'_s L}{2}$$

$$M_A = \frac{P'_s L^2}{24} \left[\frac{X + 3 - 2 Y^2}{X + 1} \right]$$

$$M_B = \frac{-P'_s L^2}{12} \frac{(X + Y^2)}{(X + 1)}$$

$$M_C = \frac{P'_s L^2}{24} \frac{[Y^2 (3X + 1) - 2X]}{(X + 1)}$$

Alternatively, the expressions for M_A, M_B, M_C can be given as follows:

$$M_B = \frac{- P'_s L^2}{12} \frac{(X + Y^2)}{(X + 1)}$$

$$M_A = \frac{P'_s L^2}{8} + M_B$$

$$M_C = \frac{P'_s B^2}{8} + M_B$$

NOTE — Minus sign denotes tension on inside face of the ring.

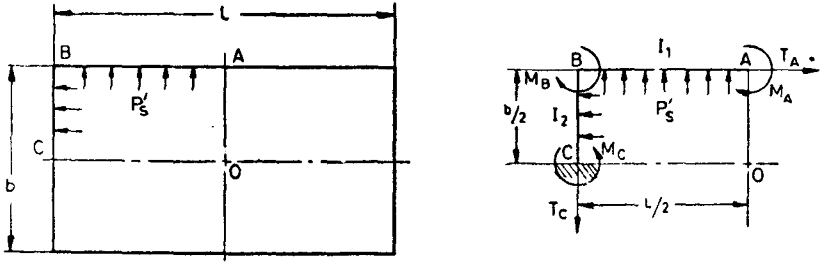
where

$$X = \frac{I_2}{B} \times \frac{L}{I_1}$$

$$Y = \frac{B}{L}$$

I_1 and I_2 = Moments of inertia of the ring as shown in Fig. 4B.

The values of M_A, M_B and M_C in terms of $\frac{I_2}{I_1}$ and Y are given in Table 1 by expressing the moments in the form $M = \triangle P'_s L^2$.



4A 4B

FIG. 4 CLOSED RECTANGULAR RING STIFFENERS

TABLE 1 COEFFICIENT △ FOR CALCULATING THE MOMENT FOR CLOSED RECTANGULAR RINGS

(*Clause* 10.3.6.1)

$\frac{I_2}{I_1}$	$\frac{B}{L} = \Upsilon = 1$			$\Upsilon = 0·9$			$\Upsilon = 0·8$		
	M_A	M_B	M_C	M_A	M_B	M_C	M_A	M_B	M_C
1·0	0·041 6	0·083 34	0·041 66	0·049 16	0·075 84	0·025 42	0·053 99	0·070 01	0·010 06
0·9	—	—	—	0·049 58	0·075 42	0·025 83	0·055 78	0·069 22	0·010 78
0·8	—	—	—	0·050 05	0·084 95	0·026 29	0·056 66	0·068 34	0·011 66
0·7	—	—	—	0·050 56	0·074 44	0·026 28	0·057 66	0·067 34	0·012 67
0·6	—	—	—	0·051 16	0·073 84	0·027 42	0·058 80	0·066 20	0·013 81
0·5	—	—	—	0·051 84	0·073 16	0·028 09	0·060 12	0·064 88	0·015 13

$\frac{I_2}{I_1}$	$\Upsilon = 0·7$			$\Upsilon = 0·6$			$\Upsilon = 0·5$		
	M_A	M_B	M_C	M_A	M_B	M_C	M_A	M_B	M_C
1·0	0·059 16	0·065 84	− 0·004 59	0·061 65	0·063 35	− 0·018 34	0·062 50	0·062 50	− 0·031 25
0·9	0·060 26	0·064 74	− 0·003 48	0·062 99	0·062 01	− 0·017 00	0·063 98	0·061 02	− 0·029 76
0·8	0·061 49	0·063 51	− 0·002 25	0·064 52	0·060 48	− 0·015 47	0·065 70	0·059 30	− 0·028 05
0·7	0·062 91	0·062 09	− 0·000 83	0·066 27	0·058 33	− 0·013 72	0·067 69	0·057 31	− 0·026 04
0·6	0·064 54	0·060 46	0·000 80	0·068 32	0·056 68	− 0·011 67	0·070 06	0·054 94	− 0·023 67
0·5	0·066 45	0·058 55	0·002 71	0·070 75	0·054 25	− 0·009 24	0·072 91	0·052 09	− 0·020 83

10.4 Trough Stiffeners — Trough stiffeners are those which give support to hopper plate. These stiffeners are subjected to uniformly varying pressures and direct tension (*see* **9.2.1** and Fig. 1). As the load is varying, and assuming $P_{nC}/P_{nB} = \gamma$ and a unit length of the bunker, the distance y from the point B and the bending moment at this point are given as follow:

$$y = kL, \text{ and}$$
$$M_y = \psi P_{nB} L^2$$

where L is the actual length of the trough stiffener. Values of k and ψ for different values of γ are given in Table 2.

TABLE 2 VALUES OF COEFFICIENT ψ AND k FOR DETERMINING THE MAXIMUM MOMENT IN HOPPER STIFFENERS

γ	k	ψ
0·00	0·422 6	0·064 1
0·25	0·451 6	0·078 9
0·50	0·472 6	0·094 0
0·75	0·490 4	0·109 4
1·00	0·500 0	0·125 0
1·25	0·509 2	0·140 6
1·50	0·516 6	0·156 4
1·75	0·522 8	0·172 2
2·00	0·527 6	0·188 1
2·50	0·535 2	0·219 9
3·00	0·540 8	0·251 7
4·00	0·548 5	0·315 5

10.4.1 Coupled with this bending moment, there will be the direct tension having the value:

$$T_y = T_B - \left[P_{tB} . y - (P_{tB} - P_{tC}) \frac{y^2}{2L} \right]$$

where P_{tB} and P_{tC} are tangential pressures at B and C respectively, and T_y = direct tension at a distance y from B.

The moment M_y and the direct tension T_y shall be multiplied by the centre to centre distance of the stiffeners to give the actual design values required to proportion the stiffeners.

10.4.2 Where T-type stiffeners are employed, the width of skin plate considered for composite action shall be as follows:

a) when s/t is less than 40, width $= s$, where $s =$ spacing between stiffeners and $t =$ thickness of skin plate.

b) when s/t is equal to or more than 40, width shall not be more than 40 t.

In any event the distance between centres of successive stiffeners shall not exceed 80 t.

10.4.3 The skin plate in the hopper portion carries the entire load due to P_V and P_W. They shall be designed for this load in addition to the moment it will have to resist in spanning between stiffeners. The connections between the plate and the top beams shall also be designed to carry these additional loads.

11. STRUCTURAL DESIGN RECOMMENDATIONS FOR SILOS

11.1 The wall and the hopper of the silo shall be designed to resist the forces specified in **9.4** and **9.5**.

11.2 The stress so calculated in the wall plate shall be within the permissible limits specified in IS : 800-1962*. Stresses due to direct load and longitudinal loads if any shall also be considered while determining the thickness of the wall plate.

11.3 Stiffeners — In order to prevent local buckling (wrinkling) of the plates the silo shall be provided with circular and vertical stiffeners.

11.3.1 For silos with height not exceeding twice the nominal diameter, horizontal stiffeners shall be provided at a spacing not exceeding 1 500 mm. Vertical stiffeners staggered in different panels shall be provided at 3 000 mm spacing. The width of the stiffener plate shall be 100 mm and the thickness shall be equal to the thickness of shell or 6 mm whichever is more.

11.3.2 Where the height exceeds twice the nominal diameter, stiffeners shall be provided as indicated in **11.3.1**, but the spacing shall not exceed 100 t or 1 000 mm whichever is less, t is the thickness of the plate.

11.3.3 The thickness of the plate shall be decided taking into consideration the effect of stiffeners.

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*Code of practice for use of structural steel in general building construction (*revised*).

12. MINIMUM THICKNESS OF PLATE

12.1 The minimum thickness of plate excluding corrosion allowance shall be 6 mm in the case of skin plate and 5 mm in the case of stiffeners.

13. CORROSION ALLOWANCE

13.1 Depending upon the exposure to atmosphere corrosion allowance on wall plate thickness shall be as follows:

Condition of Exposure	*Allowance* mm
a) Completely exposed to atmosphere and no lining	5
b) Completely exposed but lined inside	4
c) Not exposed to atmosphere but not lined inside	1·5
d) Not exposed to atmosphere and lined inside	No allowance

13.2 Corrosion allowance shall not be taken into consideration for stress calculations.

13.3 Where the atmosphere is polluted with corrosive substances special allowance for corrosion shall be made depending on the degree of corrosion expected.

13.4 Where stored material induces wear and tear and/or affects the plates due to chemical reaction special precaution against corrosion shall be taken by providing suitable lining.

14. CORNER PLATES

14.1 In order to prevent stagnation of stored material at the corners and also to facilitate easy flow corner plates shall be provided, and the minimum thickness shall be 6 mm.

15. TEMPERATURE EFFECTS

15.1 Stress due to temperature difference between the inside and outside of the bins shall be calculated and accounted for in the design. Where temperature stress is substantial, for example, in multi-compartment bins and battery of bins, detailed investigation shall be carried out on the effect of temperature variation.

15.2 Temperature Stresses — Temperature stresses are introduced in the bin structure mainly by filling the bin with the material which is either hot to start with or becomes hot later. The change in the atmospheric temperature may also lead to temperature stresses. Such stresses can generally be controlled to a satisfactory limit by suitably designing the bin or by providing suitable insulation.

16. FABRICATION

16.1 For fabrication the provisions contained in IS : 800-1962*, IS : 816-1968† and IS : 823-1964‡ shall apply.

16.2 In bins of welded construction the junction of walls inside the bin should be continuously welded to effect complete sealing, even if such continuous welding is not required from strength point of view. This is to ensure that moisture does not enter the stored material and that the stored materials do not leak out.

16.3 In the case of members outside the bin structure, for example stiffeners, intermittent welding may be adopted.

17. CONSTRUCTION DETAILS

17.1 Typical construction details of bins are given in Fig. 5 to 16 for information.

17.2 A bunker with main vertical stiffeners is shown in Fig. 5. The use of main horizontal stiffeners is shown in Fig. 6.

17.3 Typical details of hopper bottom are shown in Fig. 7.

17.4 The typical details of the bunker where the side walls are designed as deep beams are shown in Fig. 8. The details of hopper construction are also shown.

17.5 The typical connection details of the hopper to the vertical wall with main vertical stiffener are illustrated in Fig. 9. A box girder is employed as a horizontal stiffener at the junction of hopper and main wall. Similar details but the vertical walls with horizontal main stiffener are shown in Fig. 10.

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*Code of practice for use of structural steel in general building construction (*revised*).

†Code of practice for use of metal arc welding for general construction in mild steel (*first revision*).

‡Code of procedure for manual metal arc welding of mild steel.

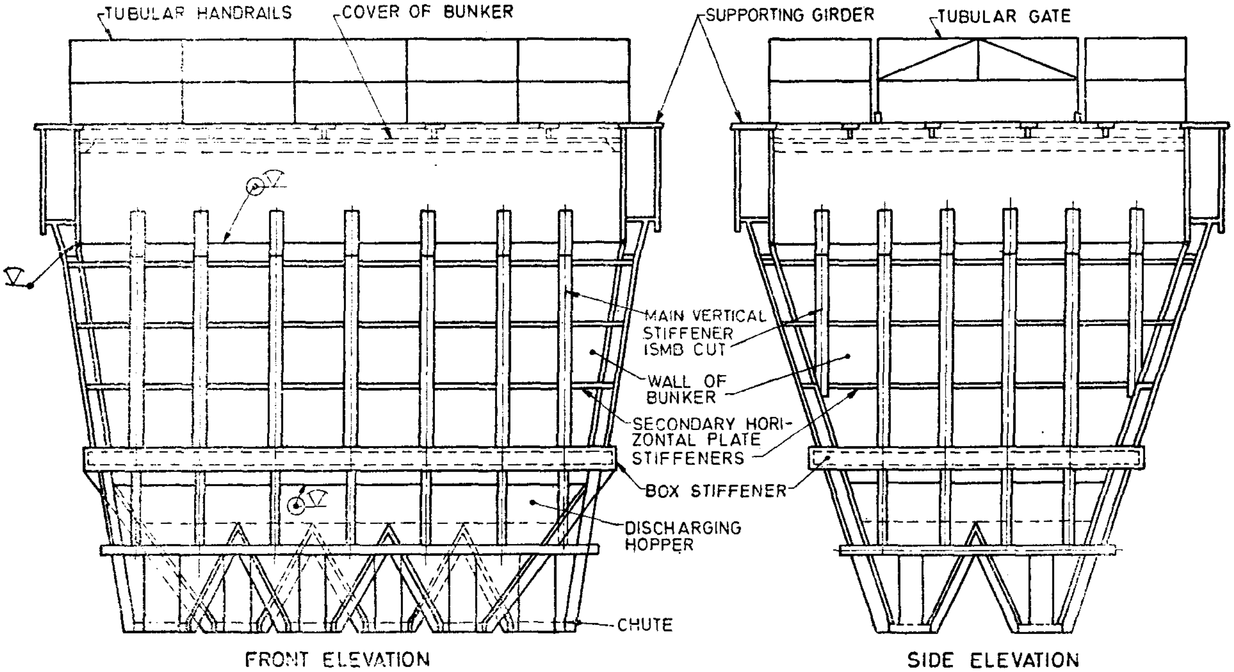


FIG. 5 TYPICAL DETAIL OF STEEL BUNKER WITH HOPPER BOTTOM (WITH MAIN VERTICAL STIFFENERS)

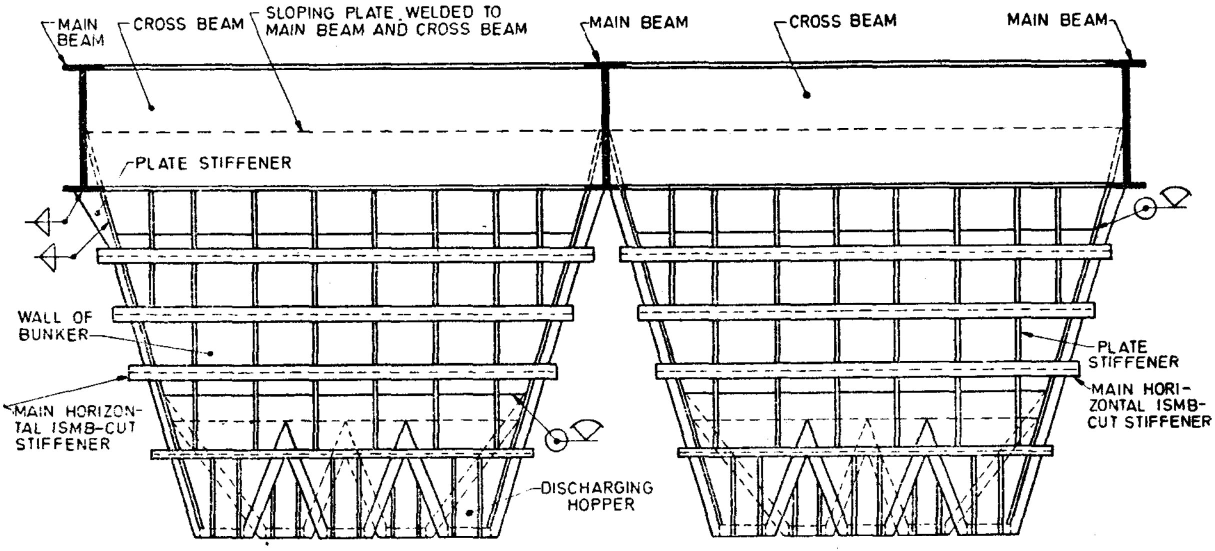

MAIN BEAM
CROSS BEAM
SLOPING PLATE WELDED TO MAIN BEAM AND CROSS BEAM
MAIN BEAM
CROSS BEAM
MAIN BEAM
PLATE STIFFENER
WALL OF BUNKER
MAIN HORIZONTAL ISMB-CUT STIFFENER
DISCHARGING HOPPER
PLATE STIFFENER
MAIN HORIZONTAL ISMB-CUT STIFFENER

FIG. 6 TYPICAL DETAIL OF STEEL BUNKER WITH HOPPER BOTTOM (WITH MAIN HORIZONTAL STIFFENERS)

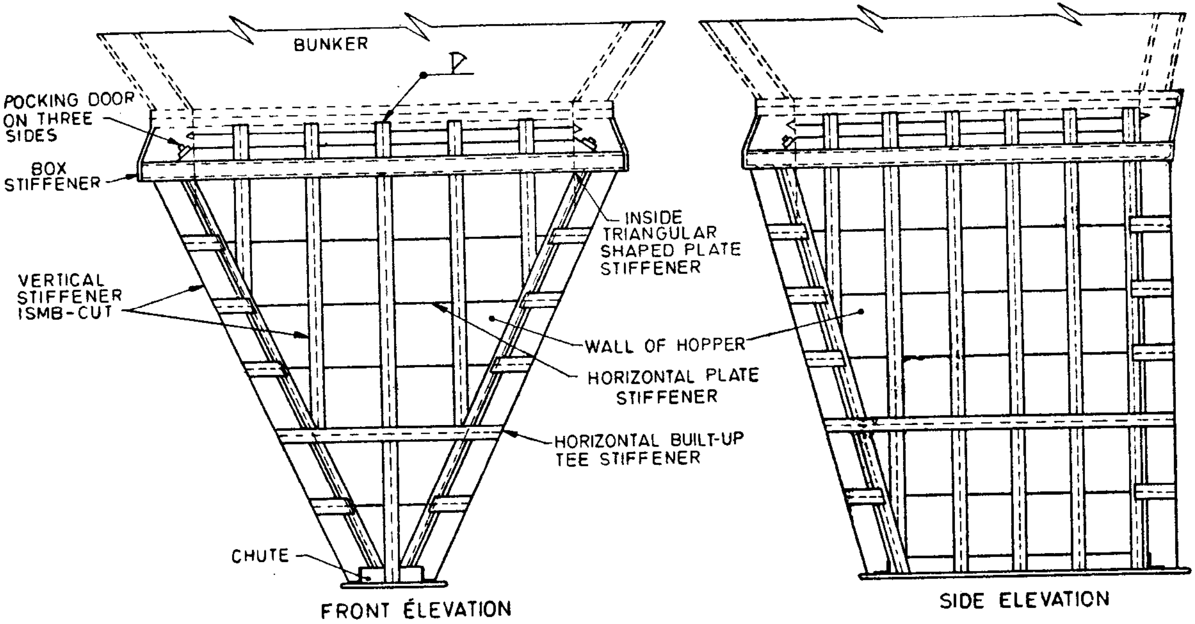

BUNKER
POCKING DOOR ON THREE SIDES
BOX STIFFENER
INSIDE TRIANGULAR SHAPED PLATE STIFFENER
VERTICAL STIFFENER ISMB-CUT
WALL OF HOPPER
HORIZONTAL PLATE STIFFENER
HORIZONTAL BUILT-UP TEE STIFFENER
CHUTE
FRONT ÉLEVATION
SIDE ELEVATION

FIG. 7 TYPICAL DETAIL OF BOTTOM HOPPER OF STEEL BUNKER

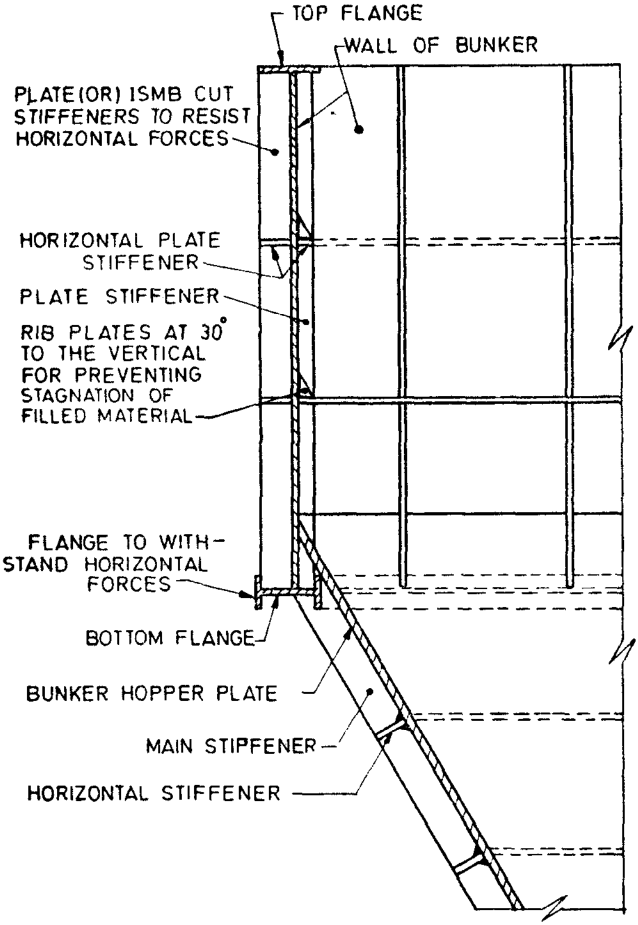

TOP FLANGE
WALL OF BUNKER
PLATE (OR) ISMB CUT STIFFENERS TO RESIST HORIZONTAL FORCES
HORIZONTAL PLATE STIFFENER
PLATE STIFFENER
RIB PLATES AT 30° TO THE VERTICAL FOR PREVENTING STAGNATION OF FILLED MATERIAL
FLANGE TO WITHSTAND HORIZONTAL FORCES
BOTTOM FLANGE
BUNKER HOPPER PLATE
MAIN STIPFENER
HORIZONTAL STIFFENER

Fig. 8 Typical Connection Details of Side Walls, Designed as Deep Beam

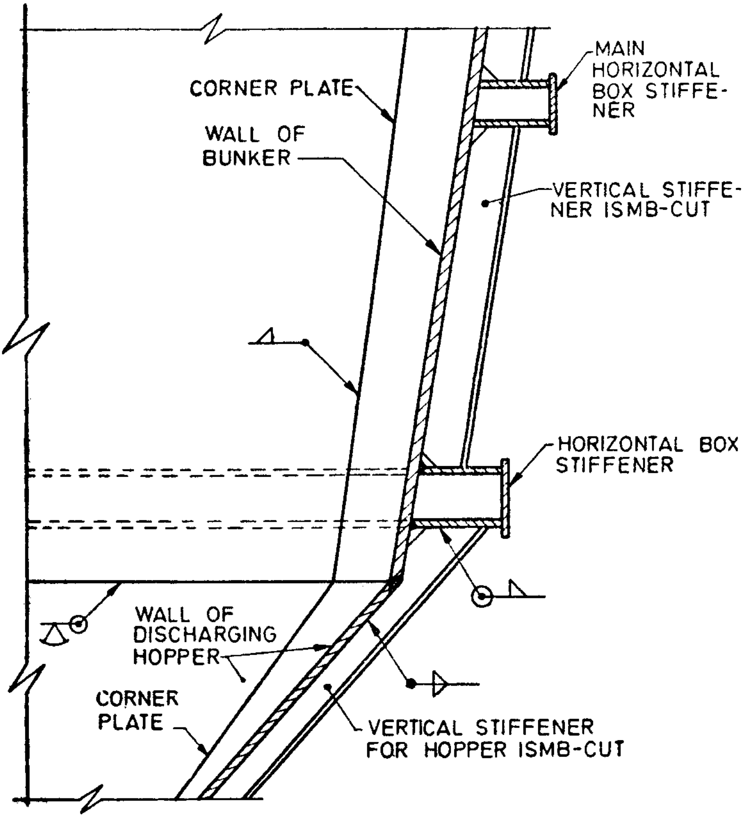

MAIN HORIZONTAL BOX STIFFENER
CORNER PLATE
WALL OF BUNKER
VERTICAL STIFFENER ISMB-CUT
HORIZONTAL BOX STIFFENER
WALL OF DISCHARGING HOPPER
CORNER PLATE
VERTICAL STIFFENER FOR HOPPER ISMB-CUT

FIG. 9 TYPICAL DETAILS OF DISCHARGING HOPPER CONNECTION (WITH MAIN HORIZONTAL BOX STIFFENERS AND SECONDARY VERTICAL STIFFENERS)

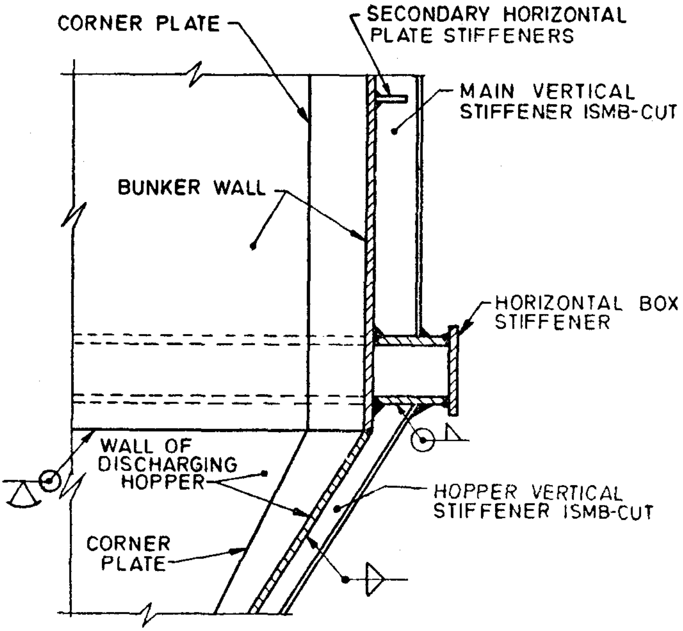

CORNER PLATE
SECONDARY HORIZONTAL PLATE STIFFENERS
MAIN VERTICAL STIFFENER ISMB-CUT
BUNKER WALL
HORIZONTAL BOX STIFFENER
WALL OF DISCHARGING HOPPER
HOPPER VERTICAL STIFFENER ISMB-CUT
CORNER PLATE

FIG. 10 TYPICAL DETAILS OF DISCHARGING HOPPER CONNECTION (WITH MAIN VERTICAL STIFFENERS AND SECONDARY HORIZONTAL PLATE STIFFENERS)

17.6 In Fig. 11 is shown a method of connecting the bunker to the main beam without transferring to it the moment and torsion.

17.7 The typical details of connecting the main horizontal stiffeners to the main supporting box girders are shown in Fig. 12. In Fig. 13 similar details with main vertical stiffeners are shown. In Fig. 14 the main supporting beam is a build up I-section.

17.8 Typical details of hopper of a sulphur bunker and typical details of a rock phosphate silo are shown in Fig. 15 and Fig. 16 respectively.

18. LINING AND INSULATION

18.1 The skin plate which is of mild steel does not normally require any insulation except for the bottom hopper portion where constant flow of material result in wear and tear. Lining may, however, be provided to prevent corrosion due to presence of moisture and of corrosive substance in the stored material.

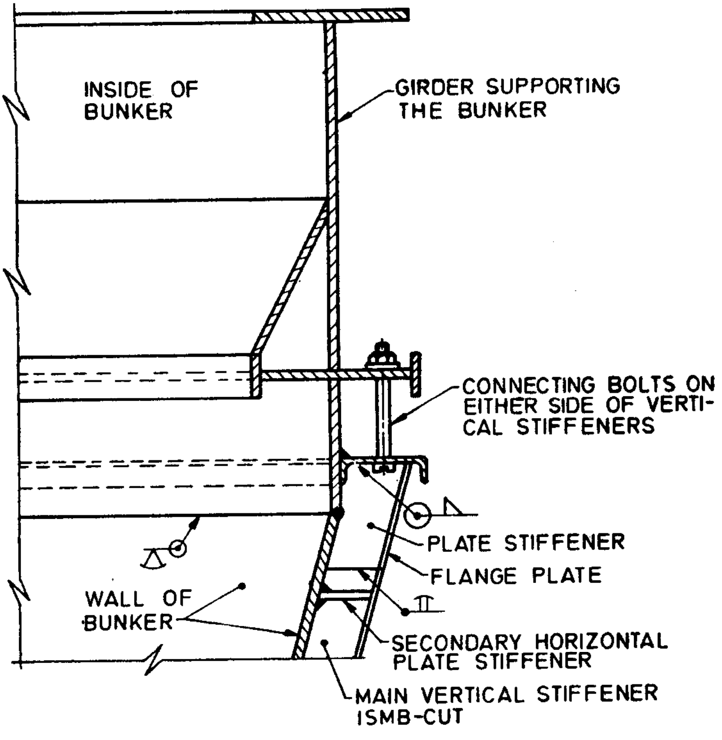

INSIDE OF BUNKER
GIRDER SUPPORTING THE BUNKER
CONNECTING BOLTS ON EITHER SIDE OF VERTICAL STIFFENERS
PLATE STIFFENER
FLANGE PLATE
WALL OF BUNKER
SECONDARY HORIZONTAL PLATE STIFFENER
MAIN VERTICAL STIFFENER ISMB-CUT

FIG. 11 TYPICAL SUPPORTING DETAILS OF BUNKER WITH MAIN SUPPORTING BEAM

(VERTICAL STIFFENER WITHOUT TRANSFERRING TORQUE TO THE MAIN BEAM)

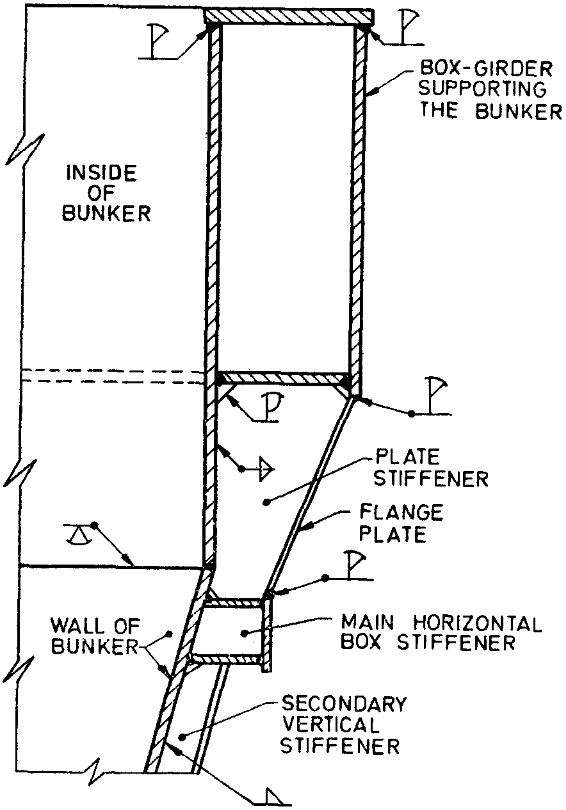

BOX-GIRDER SUPPORTING THE BUNKER
INSIDE OF BUNKER
PLATE STIFFENER
FLANGE PLATE
MAIN HORIZONTAL BOX STIFFENER
WALL OF BUNKER
SECONDARY VERTICAL STIFFENER

FIG. 12 TYPICAL SUPPORTING DETAILS OF BUNKER WITH MAIN SUPPORTING BEAM

(WITH MAIN HORIZONTAL BOX STIFFENERS AND SECONDARY VERTICAL STIFFENERS)

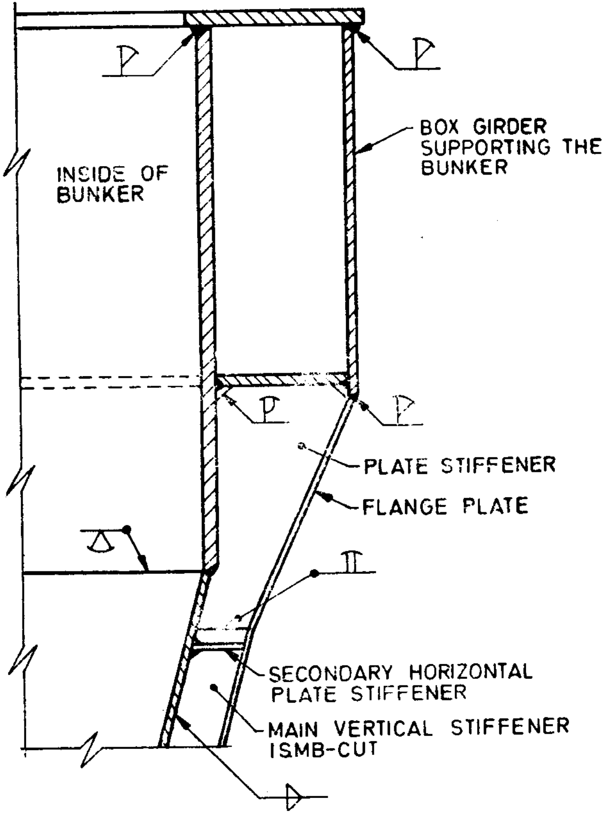

BOX GIRDER SUPPORTING THE BUNKER
INSIDE OF BUNKER
PLATE STIFFENER
FLANGE PLATE
SECONDARY HORIZONTAL PLATE STIFFENER
MAIN VERTICAL STIFFENER ISMB-CUT

FIG. 13 TYPICAL SUPPORTING DETAILS OF BUNKER WITH MAIN SUPPORTING BEAM (WITH MAIN VERTICAL ISMB CUT STIFFENER AND SECONDARY HORIZONTAL PLATE STIFFENERS)

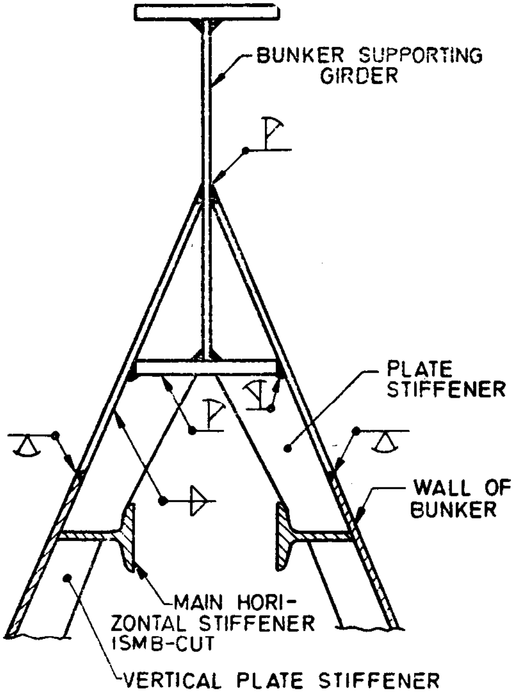


FIG. 14 TYPICAL CONNECTION DETAILS OF WALL OF BUNKER WITH THE SUPPORTING GIRDER

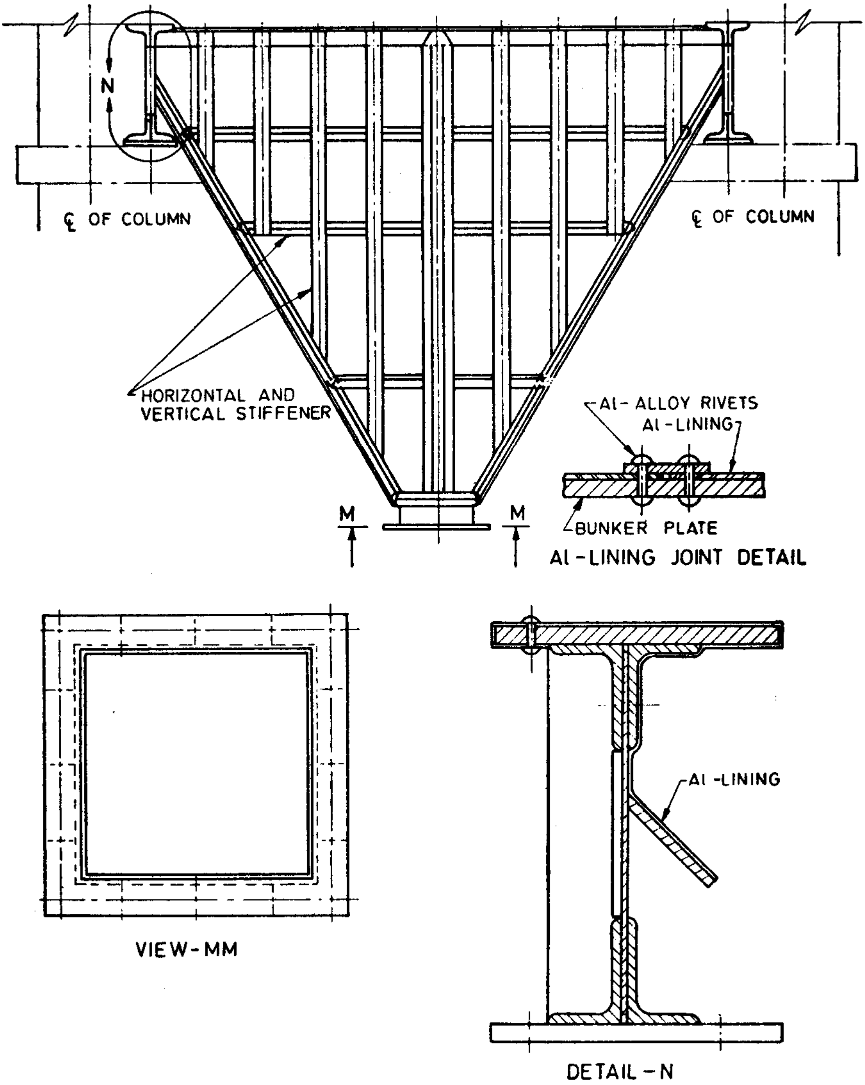


FIG. 15 TYPICAL DETAILS OF A SULPHUR BUNKER

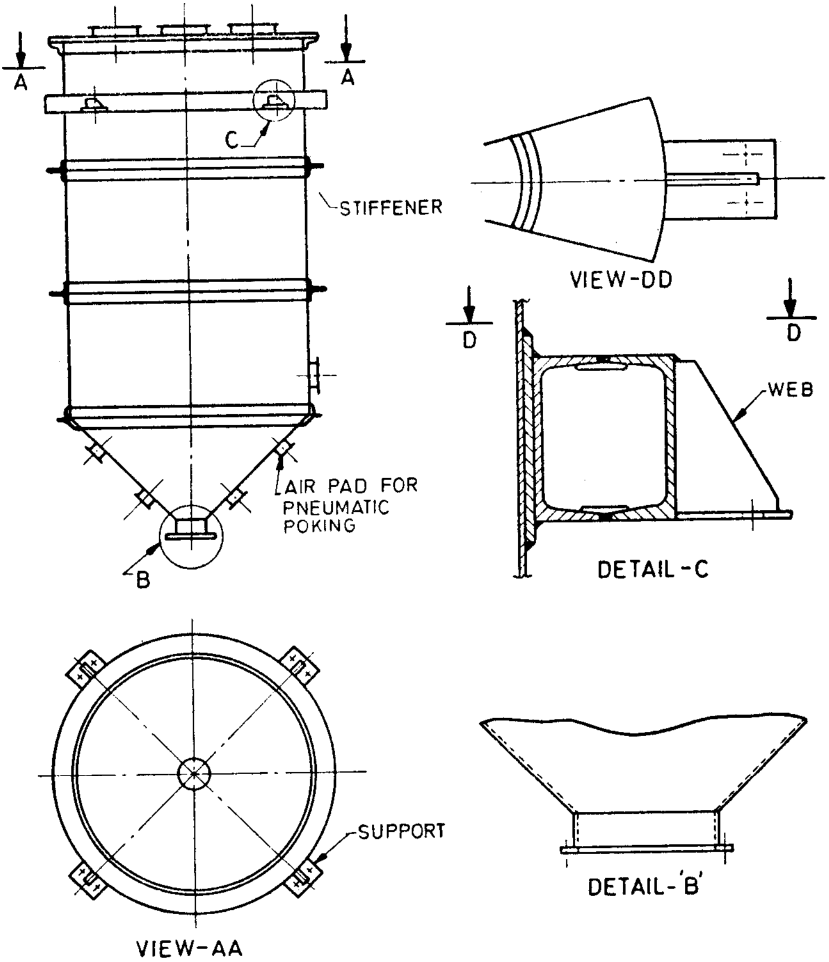


FIG. 16 TYPICAL DETAIL OF A ROCK PHOSPHATE SILO

18.1.1 It is very essential that the proper value of wall friction is taken into consideration depending upon the service requirements.

18.2 Where no lining is contemplated, the thickness of the plate shall be increased by 1·5 to 5 mm to allow for corrosion and wear (*see* **13.1**).

18.3 Concrete Lining — Concrete, the most common lining material, is applied by gunniting. Mild steel angle sections and wire nails are welded into the surface of the skin plate to effect the necessary bond. While mixing concrete hardening compound may be added to increase the wear resistance properties. The concrete surface may also be hardened by subjecting the fresh surface to a vacuum pressure. The entrapped air and moisture shall be removed thus making the surface hard and wear resisting.

18.4 Lining with Mild Steel Plates — Mild steel plates 5 mm thick are fitted over the skin plates. As they wear out new units are replaced. This is one of the most inexpensive method of lining and is, therefore, used extensively. The size of plate is so chosen that it can be handled by single person.

18.5 Lining with Stainless Steel — The skin plates are lined with stainless steel sheets or aluminium sheets where corrosion is high or where stored material like wheat flour requires hygienic storing or where the mild steel surface will have an adverse effect on the stored material. Normally sheets of 1·6 to 3·15 mm thickness are used for lining.

18.6 Acid Resisting Tiles — Acid resisting tiles are provided where the stored material being acidic will corrode the skin plate. The tiles are set in acid resisting mortar and fixed with lugs and studs welded on to the bin wall.

18.7 Angles Welded to Bin Walls — Small size (45 × 45 × 5 mm) angles are welded on to the inside of the bin wall surface at intervals. The angles retain the stored material to a minimum of its depth and thus indirectly provide a protecting method.

18.8 Glass Lining — Glass is sometimes used as lining material. In addition to giving protection to the surface, glass minimizes the friction between the bunker wall and the stored material, thus facilitating easy flow of material.

18.9 Insulation — Bin walls shall be insulated where the temperature of stored material is more than the ambient temperature. The insulation shall be properly selected to work as a lining material.

19. SUPPORTING STRUCTURES

19.1 In Appendix A are given some details of design of structures supporting bins.

APPENDIX A

(*Clause* 19.1)

SUPPORTING STRUCTURES FOR BINS

A-0. GENERAL

A-0.1 The method of supporting the bins depends on the location of the bins and the purpose to which it is intended.

A-0.2 In case the bins are provided in the construction site for storing cement, sand and aggregate or for storing food grains or in the colleries, they should be supported by columns with provision for filling the bins and also for removing the materials.

A-0.3 The height of the bins opening at the bottom should be fixed depending on the capacity and the method of discharging the stored materials.

A-0.4 The materials may be conveyed through chutes by gravity or emptied into the lorries or small wagons. Accordingly, the bottom of the hopper shall be kept 3 to 5 m above ground level and properly supported.

A-1. DESIGN

A-1.1 In addition to the forces exerted by the filled material, the forces due to wind or seismic force should be considered in proportioning the supporting columns and beams.

A-1.2 If the bins are circular, it shall be advantageous to support them at the waist. This is normally done by providing a ring beam at this level which in turn is supported on columns. The ring beam will be subjected to axial force, bending, torsion and shear.

The ring compression P_c (the off setting lateral thrust of the filling is not taken into account) is calculated by the following formula:

$$P_c = W_d \cot \theta$$

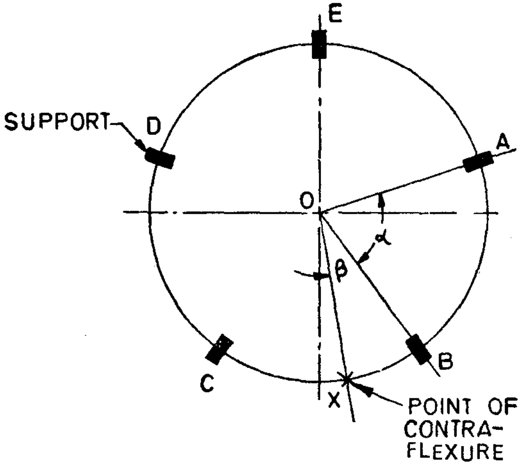
where

W_d = total weight of bin with its contents and self weight of the ring beam, and

θ = slope of hopper walls.

A-1.3 The design shall be based on the maximum bending moment which occurs at the support. The torsional moment is zero at support and maximum at the point of contraflexure.

The value of the bending moment at support M_s and mid span M_m, the torsional moment M_t and the location of the point of contraflexure X on the ring of radius r_2 may be calculated from Table 3 (*see* Fig. 17).



O = the centre of the circle on which the supports lie
A, B, C, D, E = supports
X = point of contraflexure
α = angle at the centre subtended by the two adjacent supports
β = angle at the point of contraflexure and the adjacent support make at the centre

FIG. 17 RING BEAM SUPPORTING THE BUNKER

A-1.4 The design of the column and beam shall be in accordance with IS : 800-1962*.

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*Code of practice for use of structural steel in general building construction (*revised*).

TABLE 3 BENDING MOMENTS AND TORSIONAL MOMENTS IN SUPPORTING RING BEAMS

(*Clause* A-1.3)

No. of Columns n	Angular Spacing of Supports α (Degrees)	Load at Column Support W_d/n	Max Shear $W_d/2n$	M_s	M_m	β	M_t
3	120	0·334 W_d	0·167 W_d	−0·062 93 $W_d \cdot r_2$	+0·033 29 $W_d \cdot r_2$	25°-48′	0·013 17 $W_d \cdot r_2$
4	90	0·250 W_d	0·125 W_d	−0·034 15 $W_d r_2$	+0·017 62 $W_d r_2$	19°-12′	0·005 30 $W_d r_2$
6	60	0·167 W_d	0·083 W_d	−0·014 82 $W_d r_2$	+0·007 51 $W_d r_2$	12°-44′	0·001 51 $W_d r_2$
8	45	0·125 W_d	0·063 W_d	−0·008 27 $W_d r_2$	+0·004 16 $W_d r_2$	9°-33′	0·000 63 $W_d r_2$
10	36	0·100 W_d	0·050 W_d	−0·005 27 $W_d r_2$	+0·002 65 $W_d r_2$	7°-37′	0·000 32 $W_d r_2$
12	30	0·083 W_d	0·041 W_d	−0·003 65 $W_d r_2$	+0·001 90 $W_d r_2$	6°-21′	0·000 185 $W_d r_2$

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(Common to all Offices)

Central Laboratory:	Telephone
Plot No. 20/9, Site IV, Sahibabad Industrial Area, SAHIBABAD 201010	8-77 00 32

Regional Offices:

Central : Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002	323 76 17
*Eastern : 1/14 CIT Scheme VII M, V.I.P. Road, Maniktola, CALCUTTA 700054	337 86 62
Northern : SCO 335-336, Sector 34-A, CHANDIGARH 160022	60 38 43
Southern : C.I.T. Campus, IV Cross Road, CHENNAI 600113	235 23 15
†Western : Manakalaya, E9 Behind Marol Telephone Exchange, Andheri (East), MUMBAI 400093	832 92 95

Branch Offices:

'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMEDABAD 380001	550 13 48
‡Peenya Industrial Area, 1st Stage, Bangalore - Tumkur Road, BANGALORE 560058	839 49 55
Gangotri Complex, 5th Floor, Bhadbhada Road, T. T. Nagar, BHOPAL 462003	55 40 21
Plot No. 62-63, Unit VI, Ganga Nagar, BHUBANESHWAR 751001	40 36 27
Kalaikathir Buildings, 670 Avinashi Road, COIMBATORE 641037	21 01 41
Plot No. 43, Sector 16 A, Mathura Road, FARIDABAD 121001	8-28 88 01
Savitri Complex, 116 G. T. Road, GHAZIABAD 201001	8-71 19 96
53/5 Ward No. 29, R. G. Barua Road, 5th By-lane, GUWAHATI 781003	54 11 37
5-8-58C, L. N. Gupta Marg, Nampally Station Road, HYDERABAD 500001	20 10 83
E-52, Chitaranjan Marg, C-Scheme, JAIPUR 302001	37 29 25
117/418 B, Sarvodaya Nagar, KANPUR 208005	21 68 76
Seth Bhawan, 2nd Floor, Behind Leela Cinema, Naval Kishore Road, LUCKNOW 226001	23 89 23
Patliputra Industrial Estate, PATNA 800013	26 23 05
T. C. No. 14/1421, University P. O. Palayam, THIRUVANANTHAPURAM 695034	6 21 17
NIT Building, Second Floor, Gokulpat Market, NAGPUR 440010	52 51 71
Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	32 36 35

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*Sales Office is at 5 Chowringhee Approach, P. O. Princep Street, CALCUTTA 700072	27 10 85
†Sales Office is at Novelty Chambers, Grant Road, MUMBAI 400007	309 65 28
‡Sales Office is at 'F' Block, Unity Building, Narashimaraja Square, BANGALORE 560002	222 39 71

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